

T. Y. Nickel
F. J. Kania

Printer Technology in IBM

Major developments in printer technology have occurred during the past twenty-five years. Improvements in such areas as performance, reliability, and product cost are described in this paper, along with many of the IBM impact printer products embodying these developments, beginning with the well-known 1403 Line Printer.

Introduction

Throughout IBM's history, printer technology has represented one of the company's prime development efforts. From the typebar mechanisms of the 1920s to the present advanced non-mechanical printing schemes, IBM has been a leader in the technology of printing on business forms, tabulating cards, checks, and other specialized documents.

A major milestone in technology occurred about twenty-five years ago, when a change from electromechanical timing to electronic control implemented on the 1403 Printer made "on-the-fly" printing possible. Before this, sophisticated setup and electromechanical storage mechanisms had to be used to time the print cycle. A typical example was the 150 line-per-minute (lpm) 407 Accounting Machine, which was first delivered about 1950. This was a stand-alone, 120-print-position "intelligent" printer that could do basic arithmetic such as addition and subtraction by means of electromechanical relays and counters. The print mechanism used a rotating typewheel for each print position. Each wheel was set up for each line of printing. This print mechanism was limited by speed and mechanical reliability.

Other examples of early printer technology were the 720 and 730 wire code-rod printers. These 120-print-position printers each used 35 print wires arranged in a 5×7 matrix for character generation. A hollow "code rod" [1] about one foot long, with the diameter of a pencil, con-

tained many combinations of tiny holes around its surface area. The code rod was rotated and moved up and down to position the 35 wires in preparation for wire setup. The wires would either line up with a solid portion of the rod or would line up with a hole in the rod. The code rod was then pressed against all the wires in the print head simultaneously to generate the character to be printed. A print-fire cycle would drive the print head into the ribbon and paper to print a character. This action created high mechanical stresses and forces, and thus such mechanisms were limited by reliability for use as high-volume output printers. The 720 Printer had one print head and code rod for each four print positions and it shuttled back and forth over these four positions to print at 500 lpm. The 730 Printer had one print head and code rod for every two print positions and was rated at 1000 lpm. These printers were first delivered in 1955 in support of the IBM 700 series family of processors.

Since that time, mechanical impact printers with electronic timing and control have evolved into the two major categories, line printers and serial matrix printers, that are described in detail below.

Line printers

The transition from vertical typebars, code rods, and typewheels to high-speed printing, with high print data rates from the host system, marked the beginning of line printers. The definitive characteristic of the line printer is a print mechanism that forms a complete character with

Copyright 1981 by International Business Machines Corporation. Copying is permitted without payment of royalty provided that (1) each reproduction is done without alteration and (2) the *Journal* reference and IBM copyright notice are included on the first page. The title and abstract may be used without further permission in computer-based and other information-service systems. Permission to republish other excerpts should be obtained from the Editor.

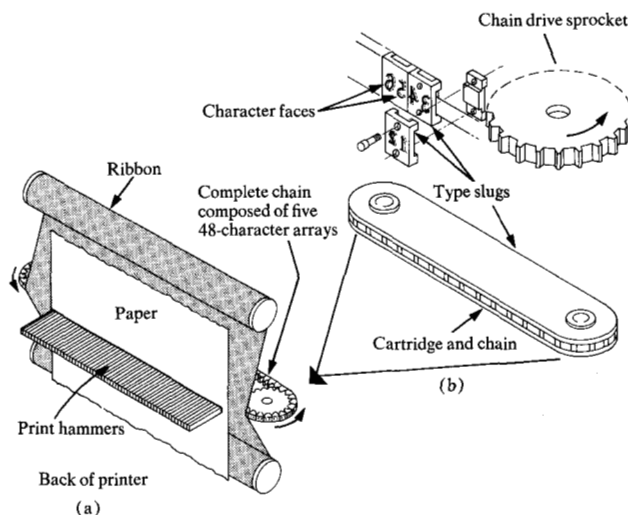


Figure 1 Schematic of "back printing" mechanism: (a) Printing mechanism schematic; (b) schematic of chain, cartridge, and slugs.

each impact of a hammer upon a type element. A control unit, using timing signals generated by the print unit, identifies the characters aligned with the print position(s) that are to be printed, allowing multiple characters in a line to be printed in a single "firing" cycle.

A line printer's rated speed is based on the number of single-spaced lines that can be printed per minute (lpm). Actual printing speed depends upon the character set used and the time required for advancing the paper between printed lines.

The quality of printed characters is subjective above certain limits, and developers of printers have struggled with its definition over the years. With no agreed-to criteria, certain parameters are optimized by the designer to provide the "best" quality for a given print speed. In general, print quality is controlled by the print media, ribbon, the actions and reactions which occur at the moment of impact, and the timing of the impact.

Important considerations in hammer design for on-the-fly printers are hammer mass and hammer velocity, impression control schemes for controlling energy at impact, hammer flight time, flight time repeatability (over time and from hammer to hammer), hammer contact time at impact, and hammer settle-out properties. Variations in type and hammer velocity due to forces of impact and drive controls can cause character misregistration. Likewise, paper motion must be completely damped out after each vertical movement and held stationary during printing to maintain proper character registration.

The line printer technologies used in IBM over the past twenty-five years include chains, bars, trains, and bands. All are variations of the principles just described and are discussed in the following sections.

● Chain printers

The "chain printer" technology was first introduced with the 1403 Printer used on the 1401 system. It used engraved type elements clamped to a flexible band formed in a closed loop similar to links in a chain. Alphabetic, numeric, and special characters were assembled on the chain in groups called character sets. As the chain traveled in a horizontal plane (driven by a drive motor), each character was printed as it was positioned opposite a magnet-driven hammer that pressed the form and ribbon against the character on the chain (see Fig. 1). This was referred to as "back printing" because a hammer behind the form pressed the form and the ribbon forward against a chain positioned in front of the form.

1403 [2]

The 1403 Printer was the first IBM chain printer developed to meet demands for greater printed output. Printing was done on continuous-form paper that moved vertically past a horizontal row of print hammers and type faces contained on a chain [3]. The forms were moved by a high-speed, paper-tape-controlled hydraulic carriage. An inked ribbon, wide enough to span all the print hammer positions, moved parallel to the paper and was interposed between the paper and the type chain. A chain was chosen (rather than a drum, for example) because it improved vertical registration and had a more uniform print density from top to bottom of a character. The chain used engraved type for high quality and moved at a constant velocity. The type characters were embossed on a series of slugs arranged in an endless loop on the chain. Initially, the type slugs were clamped on a stainless steel band [4], but this was ultimately replaced by a multi-strand "music wire" carrier band which greatly increased the life of the chain carrier.

In order to reduce vertical misregistration, the paper carriage starts and stops for each print line. A hydraulic drive unit was used because of the low friction inherent in hydraulics and its rapid response time for a start/stop operation. The paper tape mechanism [5] already in use on prior products was used to control carriage skipping motion.

Much development work was done to analyze the contact time of the hammer. This was necessary to reduce the horizontal slur of the characters which occurs when the moving type comes in contact with the ribbon and paper. The hammer had a velocity of 110 inches per second (ips) and the chain traveled at a speed of 90 ips. The

hammer magnet assembly was simple, used only a few parts, and was relatively friction free because of its unique leaf-spring suspension system. One lightweight hammer assembly was used for each print position. Because the hammer had to settle very quickly to maintain the high repetition rate, a shock-absorbing armature backstop-pad was used to provide damping. The two-spring suspension system, along with an impression control [6] bar in the hammer assembly, controlled the impression energy imparted to the paper according to the number of forms (thickness) used (see Fig. 2).

Using the hydraulic carriage, paper was advanced in either of two modes, spacing or skipping. Spacing (line-by-line advancement of the paper through the printing station) was always done at slow speed. A manual clutch and a line selection knob allowed the operator to shift gears so that the carriage could operate at six or eight lines per inch. Spacing could be single, double, or triple, and was determined by the program and the space control circuitry in the host system. Skipping (the smooth, rapid, uninterrupted flow of paper from any line on the paper to a predetermined distance below that line) was also controlled by the system, but the length of a skip was limited by the length of the carriage-control tape or forms-control buffer. Skips in excess of eight lines took place at high speed, except that the last eight lines were skipped at low speed in a mode equivalent to spacing.

To allow for more flexibility in character arrangements, an interchangeable chain cartridge was provided. This feature, in conjunction with the Universal Character Set (UCS), provided for printing any set of graphics arranged in any desired sequence on the chain.

A Numerical Print feature allowed changing from alphanumeric to numeric operation by changing the chain cartridge. Because the numeric character set is repeated more often on a chain than the alphanumeric set, the speed of a printer using this feature could be increased.

1404

The 1404 Printer, which was first delivered in 1964, was an example of one of the special uses of the 1403 chain technology. This printer filled the need for printing on pre-cut forms such as checks. It had the ability to print on two "IBM cards" in parallel (side by side), or to print on continuous forms like the 1403 Printer. The 1404 was the first IBM printer to use photoelectric emitters to control the movement of the pre-cut forms.

5203

Another family of chain printers, the 5203 Models 1, 2, and 3, was announced in 1969. The main innovation in the 5203 was the cost reduction achieved by using only one-

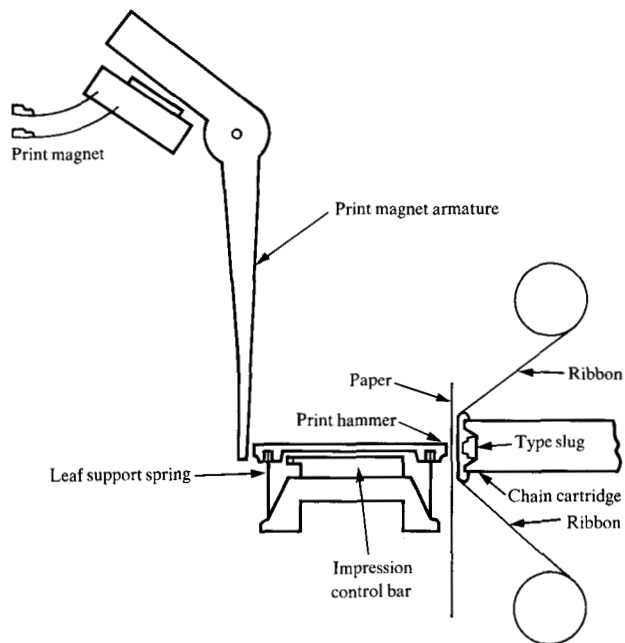


Figure 2 1403 hammer assembly.

fourth the number of hammers of the 1403, and moving them parallel to the paper so that one hammer covered four print positions.

Bar printers

1443/1445 [7]

In the early 1960s, a new computer system was being developed called the 1440, which would require a low-cost, low-speed line printer. This printer development effort resulted in the 1443 Printer, which ran at 150 and 240 lpm.

The 1443 was a "front printer" (*i.e.*, the hammers were positioned in front of the type elements rather than behind the form) and used a horizontal "typebar" mechanism for moving the type back and forth in front of the paper. The character slugs were mounted on fingers inserted into the bar [8]. These fingers were flexible so that the hammers could deflect them into the ribbon and paper.

Originally, the typebar incremented back and forth, starting and stopping in front of each print position, moving one position at a time. This scheme was difficult to control from a timing standpoint, and the mechanism tended to wear out quickly due to the high mechanical stresses, especially at the start/stop points. A reciprocating bar mechanism was consequently developed which stopped only at the turnaround points after all characters had passed in front of each print position. This had much

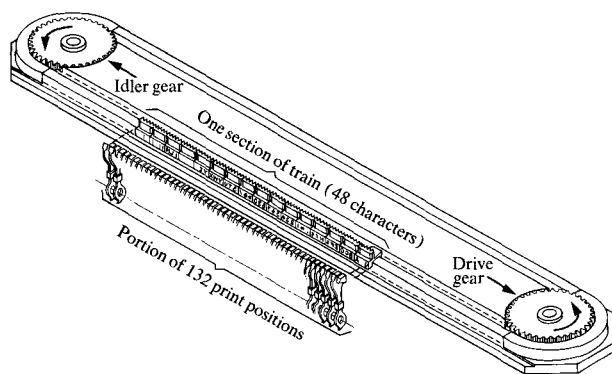


Figure 3 Schematic of "train printing" mechanism. (The complete train is composed of five sections of 80 type slugs with three characters per slug.)

less wear and longer life and traveled at the relatively slow speeds of 16 and 25 ips. The ribbon, unlike that in the 1403, was a reel-to-reel system similar to that in a typewriter, for lower cost.

The carriage mechanism used magnetic friction clutches, not a hydraulic unit, but it retained a paper tape mechanism as a means of controlling carriage skipping. The magnetic friction clutches were found to be affected by temperature and humidity and were replaced in later printers, *e.g.* the 2203, by dc servo motors and stepper motors.

The 1445 Printer was a modification of the 1443 Printer, developed for printing the high-quality MICR banking magnetic font using a special film ribbon.

2203

A higher-speed hammer unit had been under development. This unit provided a lighter hammer with less friction in the moving parts, and became the basis for the 350-lpm 2203 Bar Printer, which otherwise used the typebar technology and mechanical layout of the 1443 Printer. The carriage drive was changed from the clutch drive to a stepper motor drive for reliability, although the carriage paper tape control was still used.

The speed of the horizontal typebar was increased from 25 to 41 ips to obtain higher performance. The typebar was driven by a printed-circuit dc servo motor for higher reliability and performance. The ribbon drive was changed from a clutch/brake mechanism to a 60-cycle ac stepper motor to reduce the complexity of the mechanical system, again for reliability. In both the 2203 and 1443 Printers the type segments in the typebar were user-re-

placeable to provide for font changes and replacement of worn or broken parts. Much development went into the design of the typebar segments, since the higher speeds of both the hammer and the typebar itself required special surface treatment and polishing to relieve stress concentration points.

• Train printers

The chain technology was limited in throughput due to the speed of the chain itself. In trying to obtain more lines per minute the chain had to be driven at higher velocities, but could not mechanically sustain such speeds. A dramatic increase in throughput was achieved by replacing the flexible chain holding the type elements together. Instead of a chain of type, individual print slugs were assembled in a "train," restrained in a machined track, and driven by a gear at high speeds [9]; see Fig. 3. This was termed "train printing" technology, as it resembled railroad cars on a track being pushed by a drive source. The first train-technology printer was the 1403 N1, introduced in 1964. Significant improvements and design changes were made to produce the train, and a much lighter-weight hammer was used [10].

Characteristics of front printing Also studied in conjunction with train technology was front-vs-back printing. Front printing places the hammer in front of the ribbon and type with the paper in the rear against a fixed platen [11]. This format eliminates much of the air in multi-part forms and gives minor forms compression, resulting in more repeatable hammer flight distance and energy expended on the paper; *i.e.*, good print quality. Back printing has the hammers in the back of the paper and presses the paper into the ribbon and type, which minimizes the exposure of the hammer unit to the ribbon and ink. There is significant compression of multi-part forms and motion of the forms into the type. Thus the print energy is more variable than in front printing and this, coupled with a solid type-element carrier, produces lower print quality on the average. A major problem with front printing is that of getting the hammer to strike the desired type element, and then moving the hammer back quickly enough so as not to hit the next type element as the type elements move rapidly past each print position and hammer. Front printing does reduce two major print quality problems associated with back printing. It reduces "character cut-off" because the full character is always pushed into the paper, and "hammer blocking," a characteristic of back printing which causes the image of the hammer to be produced as a "halo" around the characters printed on the last part of a multi-part form.

1403 Models 3 and N1

The 1403 Models 3 and N1 were the first IBM line printers to use the higher-throughput train technology. Type speed

was increased from 90 to 206 ips and a major design change was made to the hammer unit. To reduce slur caused by the increased type speed, the contact time of the hammer was reduced by decreasing its mass. The hydraulic carriage and control tape were still used, and the response time for a line space operation was reduced to 18.5 ms, which was considered the maximum reliable performance for that hydraulic unit. The 1403 Models 3 and N1, using the "train" principle, increased printer throughput to 1100 lpm for a 48-character set. These printers offered an interchangeable train cartridge as a standard feature and the 1403 N1 featured a system of acoustically insulated covers designed to decrease the noise level. The top cover on the N1 was power-operated and opened automatically when operator intervention was required. Switches were provided for manual operation.

Improvements in paper handling were achieved by means of an adjustable power stacker. The paper stacker rolls were powered by a motor and the height of the rolls relative to the top of the paper stack was adjustable to assist the stacking. The power stacker provided a positive stacking action by pulling the paper away from the carriage tractors as it was moved past the print line, causing it to stack in a fanfolded pile below the stacker roll.

3211

The 3211 Printer, introduced in 1970, combined the proven train printer technology with front printing and high hammer energy to produce high-quality multi-part form printing (Fig. 4).

The print train and carrier are enclosed in a removable cartridge. As the print train in the cartridge revolves, the type elements pass in front of a row of print hammers to successively present every character to every hammer. The 3811 control unit, using signals from the cartridge, identifies each character before it aligns with a hammer, and activates the proper hammer as a character aligns with a position where it should print. The 3811 control unit also contains checking logic and buffers for storing print data and document control information.

Dramatic increases in performance required a faster type speed, faster carriage times, and a higher repetition rate for the hammer, as well as decreased hammer settle-out time. Much effort was put into the study of hammer dynamics to make these improvements. A new type slug was developed that was suspended on the train elements, not engraved directly on the carrier itself [11]. This resulted in a front printer with excellent print quality. Instead of a significant increase in type speed to gain higher throughput, the suspended type slug lever was used to allow the type to be spaced closer together. This, coupled

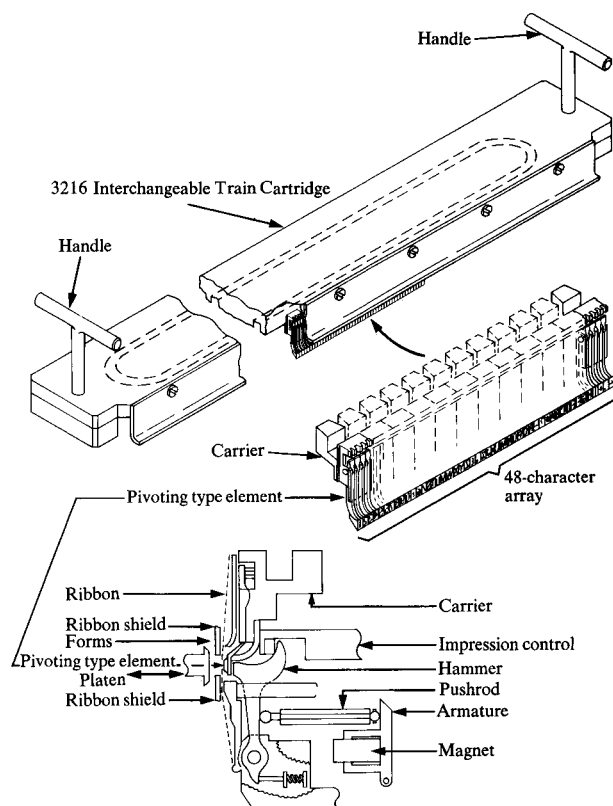


Figure 4 3211 hammer assembly and 3216 Interchangeable Train Cartridge.

with a slight increase in train speed from 206 to 224 ips, resulted in a print speed of 2000 lpm with a 48-character set. Note that hitting one type slug with a hammer at this speed is similar to running at high speed past a picket fence and trying to hit one picket, push it out, and get out of the way before striking the next picket. This was the limiting factor in further increasing lpm speed. The carriage speed required to support 2000-lpm printing was beyond the capabilities of the hydraulic carriage, and a dc "printed circuit" armature motor was used to obtain the required carriage speed and drive.

In conjunction with the need for good print quality, an oscillating platen was developed. The platen pulled back away from the form during paper motion, and pushed against the paper during printing [12]. This reduced ribbon smudging during paper motion, especially on the folds of multi-part forms, and decreased the hammer-to-platen gap during printing to reduce hammer travel distance, thus increasing the performance.

The 3211 introduced a forms control buffer, eliminating the need for a carriage paper tape that required operator

intervention and did not have the reliability needed for the high printing speeds of this printer.

A power stacker was developed to assist in paper handling, since a standard box of forms could be printed in approximately ten minutes. An electronic counter kept track of the number of forms stacked and the stacker feed rolls were raised automatically to provide optimum stacking. A simple operator control was provided to accommodate various form thicknesses. An automatic forms thickness adjustment was built into the platen to account for the different paper thicknesses. Magnetic interaction from one hammer coil to the next was reduced by shielding and armature winding orientation. Less costly, plastic-packaged hammer drivers were used to fire the hammers.

The 3211 Printer introduced many maintenance innovations, such as an automatic train oiler to lubricate the carriers, an automatic flight-time adjustment system, and a built-in vacuum system to assist in the maintenance of the printer. A control panel, built especially for the customer engineer, provided the capability of diagnosing problems without using the host system. Along with innovations in technology, the 3211 Printer subsystem introduced a combined Maintenance Analysis Procedures (MAPs)/Maintenance manual to assist the customer engineer in diagnosing failures and making repairs. In the past, these had been separate manuals, each independently controlled. The combined MAPs/Maintenance manual was kept current by releasing changes to the manual concurrently with hardware changes to the printer.

3203 [13]

The 3203 Printer, which was first delivered in 1974, offered improved reliability in the 600- to 1200-lpm range, and featured the integration of printer control logic into the printer base using more dense semiconductor technology. A unique offering of the 3203 was the Programmer Braille Printing Feature, which produced a single-run throwaway copy for the blind. The operator installed a rubber strip across the face of the hammers to create a soft platen and printed Braille with the periods on an interchangeable train cartridge by indenting the paper. A programmer had to understand the Braille system in order to generate the matrix of dots that make up a Braille cell.

• Band printers

In the late 1960s, IBM was looking for a low-cost, highly reliable printer to operate at speeds of 30 characters per second (cps) and higher. A simple print type element was desired to keep the cost down. Ability to change fonts quickly and easily, relatively slow mechanical speeds, and small vertical misregistration were also design goals.

A flexible band technology was developed that was extendable to speeds of more than 600 lpm. Flexible bands for carrying the type were a known technology at that time, and other technologies such as wheels, drums, print balls, and sticks were reviewed for desirability. The main contender was a disk printer, but this was limited in character set size and reliability. Drums and wheels tended to give vertical misregistration. To add extra characters, print wheels would have to be increased in diameter.

The band "print system" [14] was designed and developed as a total mechanism rather than as a series of major individual components such as hammer, carriage, and ribbon. This allowed tolerances which were critical and costly to be examined, and cost tradeoffs to be made and "designed in" from the start.

The hammer unit had to be low-cost, and thus could not afford one hammer for each print position. An incrementer to move the hammer unit back and forth in front of the print positions was costly and not very reliable. Therefore, the first band printer was designed with each hammer assembly wide enough to cover two print positions. It did not cover three or four positions, since the band speed would have to be greatly increased with an associated hammer response time improvement, which would be too costly. The increased density of electronics allowed the packaging of 22 hammer drivers per card, each with a 5-amp, 24-volt drive capability. This was very dense packaging for that time. Three different pulse widths on the hammer-fire electronics varied the energy applied to the hammer itself. This replaced the conventional mechanical impression control device to compensate for varying forms thickness. When the distance between the print band and hammers was increased to accommodate thicker forms, a potentiometer connected to the forms thickness control automatically increased the hammer pulse width to provide the proper density. An innovative electronics control circuit also compensated for hammer firing speed variations that resulted from temperature fluctuations or power supply changes. This control circuit changed the band speed through its stepper motor drive. The hammer unit itself was also designed so that variations in flight time needed to be adjusted only once, at initial assembly time.

The ribbon mechanism consisted of a stuffer box and a narrow, typewriter-like ribbon running horizontally in front of the print area; the mechanism was driven by the same stepper motor that drove the print band.

The carriage drive was designed with a stepper motor for increased reliability and tractors made of plastic for lower cost. A mechanical vernier on the carriage stepper

motor allowed vertical paper adjustment for positioning and loading.

3618/3288/3776

The first printer to make use of this band technology was the 3618. It ran at 155 lpm with a 48-character set and was used in the IBM 3600 banking system. This was followed closely by the 3288 Printer at 120 lpm print speed. Both used one hammer for every two print positions. These units were followed in late 1974 by the 3776, which was a keyboard-interactive printer connected to a teleprocessing line. Two speeds were possible on the 3776, 300 lpm and 400 lpm, using a standard 48-character set. To provide this higher throughput, the hammer unit had one hammer for each print position, and the unit also had more characters etched on the band at closer intervals.

5211

The 5211 Printer was a line printer that utilized the band technology and ran at speeds up to 300 lpm. This printer used a "paper clamp" device to reduce horizontal forms movement during printing and to provide better acoustics. The paper clamp, located under the print unit, holds the forms tightly against a guide during printing and is magnetically operated under control of the using system.

3262

The 3262 is the most recent series of printers using the band technology. It marks the beginning of the integration of microprocessor "intelligence" as well as printer control logic and mechanics into a single unit. Because of improved component packaging and design, certain models of the 3262 are designated as Customer Set-Up (CSU), which allows the customer to install and relocate the printer without IBM customer engineering involvement.

To maintain maximum productivity, key functional areas of the 3262 Printer are monitored constantly. When an error or failure occurs, it is automatically analyzed and an error code is displayed to the operator. Using the Operator Panel, the user is often able to solve the problem without calling a customer engineer. In addition, the printer can be detached from the processor to perform tests and measurements.

Serial matrix printers

In the late 1950s and early 1960s, the typewriter was the most popular serial-by-character printer IBM offered. On the 1050 system announced in the early 1960s, the system printer was an IBM SELECTRIC® typewriter with totally mechanical character selection. It was slow and not suitable as the console output printer for the rapidly emerging high-speed electronics systems. A new technology was needed that would be faster and more reliable. Two radically different technologies were being developed at the

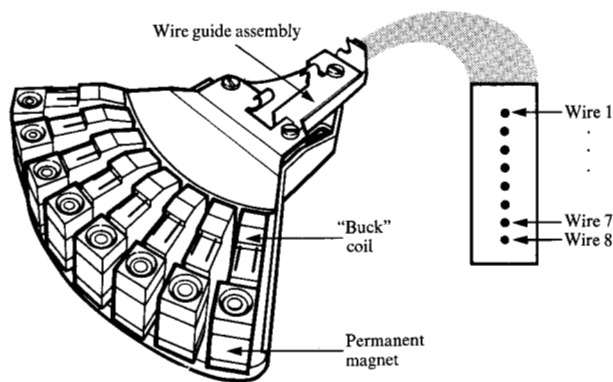


Figure 5 Wire matrix head with "no-work" magnets.

time, the hydraulic stick printer and the wire matrix printer.

The hydraulic printer was originally designed for a speed of 20 cps. At its inception, the cost of electronics for control was high, so it contained a simple electromechanical interface for attachment to the using system. In this printer, electromagnetic valves selected hydraulic logic valves which in turn selected hydraulic actuators. Most moving parts were submerged in a bath of oil. The 64-character print element was an eight-sided stick about the size of a short pencil on whose surface the characters were engraved.

However, moving fluids takes a large amount of energy and generates heat. Environmental conditions forced the installation of expensive cooling systems. Additionally, the cost of electronics was rapidly decreasing with the advent of solid state devices. The wire matrix printer under development at the same time was not only less expensive, but faster. Hydraulic units were thus abandoned in favor of the wire matrix head shown in Fig. 5 [15].

The principle of forming characters with a matrix of dots dates back to the 026 Printing Key Punch, which was developed about 1950. The dots in the characters are formed by selectively striking the ribbon and paper with the ends of small individual wires. A close inspection of the printing shows a series of dots arranged in a matrix. The dot matrix provides great character design flexibility. The original embodiment had the character dot pattern stored in the host processor with a read-only storage. The original matrix was nine bits wide by seven high, but this was later reduced to 7W × 7H, since that still gave acceptable print quality with higher print speeds and required less read-only storage.

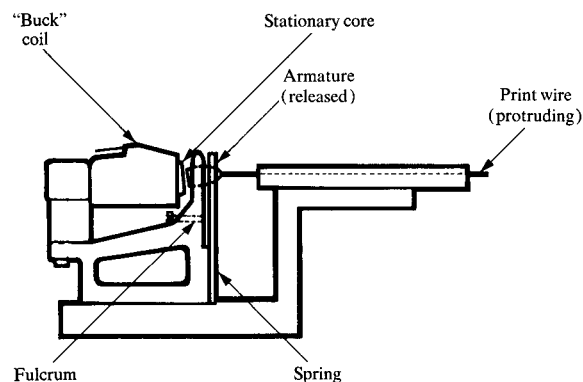


Figure 6 Configuration of no-work magnet assembly.

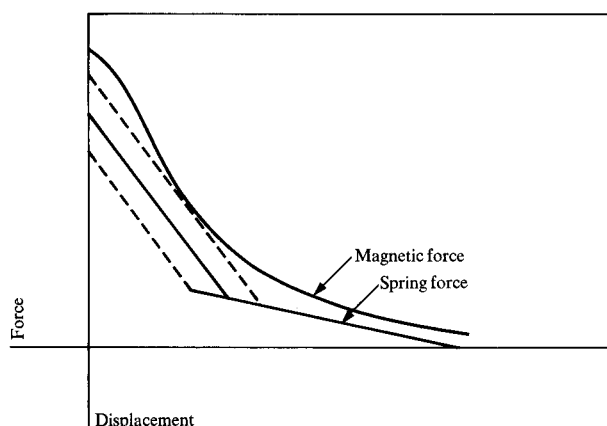


Figure 7 Armature displacement for no-work magnet firing cycle.

• No-work magnet wire matrix head

The actuator of the first wire matrix print head was a "no-work" magnet, a side view of which is shown in Fig. 6. The magnetic circuit consists of a soft magnetic structure surrounding a permanent magnet and a movable armature which is attached to a spring. When the "buck" coil is not energized, the armature is attracted to and sealed against the stationary core by the flux of the permanent magnet, and energy is stored in the spring.

Figure 7 shows the magnetic and spring forces vs armature displacement. The area under the curves represents available energy. The discontinuity, or bend, in the spring curve is caused by the fulcrum, which is adjustable. This adjustment allows for a range of stored energy, which acts as a flight time adjustment. To print, the buck coil is energized to oppose the flux of the permanent magnet, thus driving the magnetizing force to coincide with the abscissa of Fig. 7.

The no-work magnet has significant advantages over "work" magnets, as will be discussed following the description of the latter. Disadvantages, however, include the need for periodic adjustment, and wear at the adjustment points.

2213

The 2213 was delivered early in 1970 as the first user of the no-work wire matrix print head. It printed at 66 cps in one direction only and was used as the console output printer for the 2770 Data Communications System. Each wire had a cocked spring behind it, held back by a "hold" magnet. When the hold magnet's force was overcome or "bucked" by an oppositely polarized magnet, the spring's energy was released and forced the print wire against the ribbon and paper. Originally, the first engineering model had one large hold coil for all the print wires, with each wire having an individual bucking coil. This design was changed so that each wire had its own individual permanent hold magnet, a cost reduction that avoided unwanted magnetic interaction between the large hold coil and multiple bucking coils. This eliminated unwanted wire fires. This also maintained the wires in a retracted position with machine power off to allow the operator to change ribbon or load paper without first turning on the power. As seen in Fig. 5, the wires and coils are arranged horizontally in a wedge shape so that the last printed character is visible to the terminal user and not obstructed by the head itself.

A drawback associated with the wedge-shaped head is that both wire friction and the asymmetrical placement of the magnet and print wire assemblies caused the end positions to require stronger hold magnets. This design limited the overall performance of the print head.

The no-work magnet needed a spring to fire the wires, which meant that each wire mechanism had to be adjusted for variations in mass-produced parts. The magnet could stand voltage and current variations and still keep the same flight time, since the spring force was the determining factor and was constant. Early problems with this configuration were wire guide clogging and wear on the armature seal point. Both problems were resolved with the addition of a built-in oil reservoir and wicks. Another problem was to find a material for the print wires which would have a long life. Sintered tungsten carbide wires were chosen because they provided the reliability needed and did not cause ribbon wear.

Other models

Many other models of the no-work wire matrix printer were also introduced with the same printer technology during the early 1970s, including applications such as the 2222 Ledger Card Printer for the System/3 Model 6.

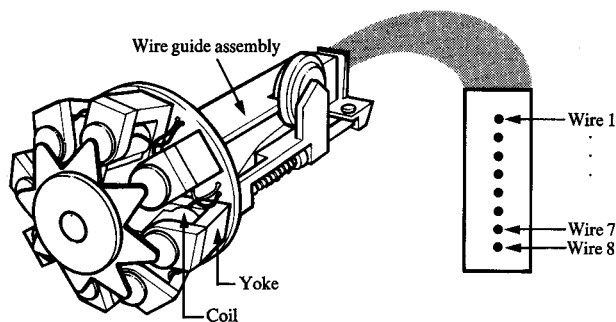


Figure 8 Wire matrix head with "work" magnets.

The 3284/3286 Printers were cost-reduced printers that used the no-work wire matrix print head. A sprocket feed similar to that of a typewriter was used for paper feed along with a solenoid/ratchet mechanism. These printers ran at 40 and 66 cps, respectively. Speeds were increased to 85 cps and 115 cps in the 5213 Printer, and tractors were used in the 5213 to increase the reliability of paper feeding and to permit the use of preprinted forms.

Considerable mechanical design effort went into the head suspension system, and a leadscrew-guidebar mechanism was chosen to ensure a high degree of parallelism between the head and the platen as the head traveled in front of the paper. The mechanism was driven by a stepper motor, and feedback pulses were provided to the motor by a transducer that sensed an emitter disk at the end of the lead screw. The wire firing positions were also controlled by the use of another rotary emitter, with an accuracy capable of distinguishing the individual points of the dot matrix within the characters themselves.

• Work magnet—head mechanism

To overcome some of the deficiencies of the earlier no-work head, a new design was developed which used the work magnet principle, as shown in Fig. 8. The most obvious difference is the cone-shaped arrangement of the print wires, so that each wire is equal in length, equidistant from the paper and the other magnets. In applications where visibility is important, the controls for head positioning can move the head sideways, away from the last printed position, allowing the last character printed to be visible to the operator.

A work magnet is essentially a solenoid consisting of a coil, a movable element (armature), and a stationary core. The armature is held away from the stationary core by a light spring until the coil is energized, at which time induced magnetic forces overcome the spring tension and

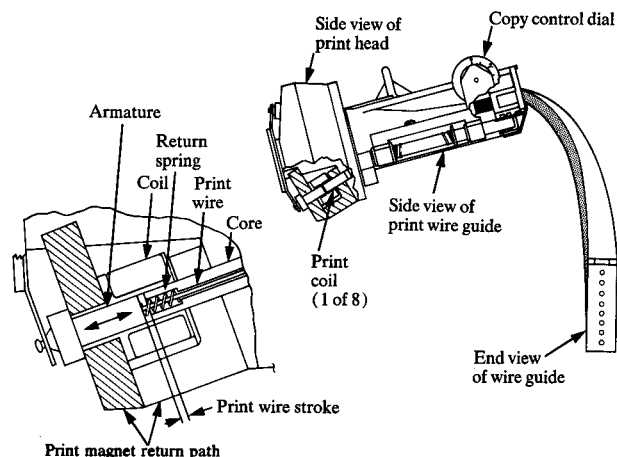


Figure 9 Configuration of work magnet assembly.

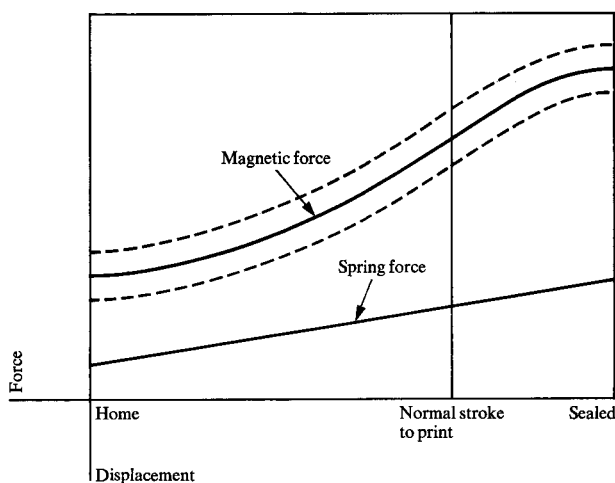


Figure 10 Armature displacement for work magnet firing cycle.

cause the armature to move. As shown in Fig. 9, a flux return path in the core contains the flux generated by the coil to eliminate interaction with adjacent magnets.

Figure 10 shows magnetic and spring forces for this type of magnet, in contrast to the no-work magnet. Notice that in this case the magnetic forces are due to the coil and do the "work." The dashed lines indicate possible changes in magnetic force due to variations in coil current.

The simplicity of this embodiment of a work magnet nullifies the need for mechanical adjustment, an obvious advantage. (However, coil current must be closely regulated to provide constant print energy and wire flight times. Also, relatively high-current drives are necessary to overcome the initially large magnetic air gap.) This new design, plus the increased use of plastic parts, gave the work magnet a cost advantage over the older no-work design. Speeds up to 120 cps were attained. This mechanism was first introduced in 1974 in the 3715 and 3767 Printers [16].

Work magnet head positioning was accomplished by means of a motor-and-belt mechanism that provided high reliability at a lower cost. The position of the head was tracked by a linear air core transformer, operating at rf frequencies, which is the width of the print traverse distance with a reference point coupled to the paper path at the left margin. This same emitter is used to locate the wire dot positions in the character matrix. It is a closed loop system driving a stepper motor. The popular 3287 Printer, including the latest four-color printer, uses this work magnet head.

Other printer technologies

Several other technologies were being pursued to develop printers for unique, special-purpose applications. A small inexpensive printer was required for application in the banking industry. (Matrix printing at that time was not in use in banking.) A mechanism using a metal disk was used in the 3610 Document Printer delivered in 1974.

A durable steel disk, which spun continuously during printing, contained etched type characters on individual fingers around its periphery. Slugs were driven against the fingers by a hammer-interposer mechanism [17]. The interposer transferred the hammer energy to the slug and also restrained the motion of the hammer so as not to hit the next finger coming around on the spinning disk. An ink roll was used to transfer ink directly to the disk. An improvement was made to the mechanism whereby the type and slug were combined into a more massive type element and swaged directly to the finger. This allowed adjacent slugs to support each other so that catching on the edge of a passbook would not damage the finger.

Another banking application required very-high-quality printing, and a disk was also used to satisfy this need. Improved print quality was obtained by stopping the disk as each character was printed and indexing the wheel (over the shortest distance, left or right) to the next character to be printed. This device was capable of printing up to 60 cps. A linear stepper motor was used to drive the print mechanism and a ribbon was used for inking. This

technology appeared in the 3613 Desk Terminal Printer used in the Japanese banking industry.

A third technology used engraved typewheels, with one typewheel for each print-character column, stacked together to form a drum. It was used in the 3608 Banking Terminal introduced in 1976 and the 3642 Industry Systems Printer introduced about the same time. The application for the 3608 Banking Terminal is to print on individual card stock or on multiple-part credit forms. The 3642 Industry Systems Printer not only prints on a variety of manufacturing documents but encodes a magnetic stripe for future information retrieval.

Summary

The past two and a half decades have produced many innovations in the field of machine printing. The era of high-speed and high-volume printing began with the 1403 family of chain and train printers of the 1960s. The 3211/3811/3216 Printer subsystem of the 1970s provided the integration of the printer, the control unit, and an interchangeable cartridge into a single cohesive package that was maintainable without the host system. The band printer technology, first introduced in 1974, provided a totally designed print system which featured low cost and high reliability. Although originally intended to satisfy low-speed (30-cps and up) applications, the band technology eventually extended up to the 600-lpm range on the 3262 Printer.

The serial matrix printer technology of the late 1960s, continuing through the 1970s, provided the high-speed printing terminals to satisfy the needs of the many industries and applications, from banking to retail outlets.

Acknowledgments

Acknowledgment is given to the following people for their assistance in preparing this article: J. G. Barcomb, G. H. Buehrmann, E. H. Darrow, J. L. Dessel, R. E. Dietl, J. E. Drejza, R. G. Gibson, R. W. Greaves, B. Griffing, J. D. Huth, M. A. Henkel, D. C. Johnson, E. I. Knowlden, F. W. Martin, S. E. Nemier, D. J. Stiles, J. C. Walsh, and J. H. Wellburn.

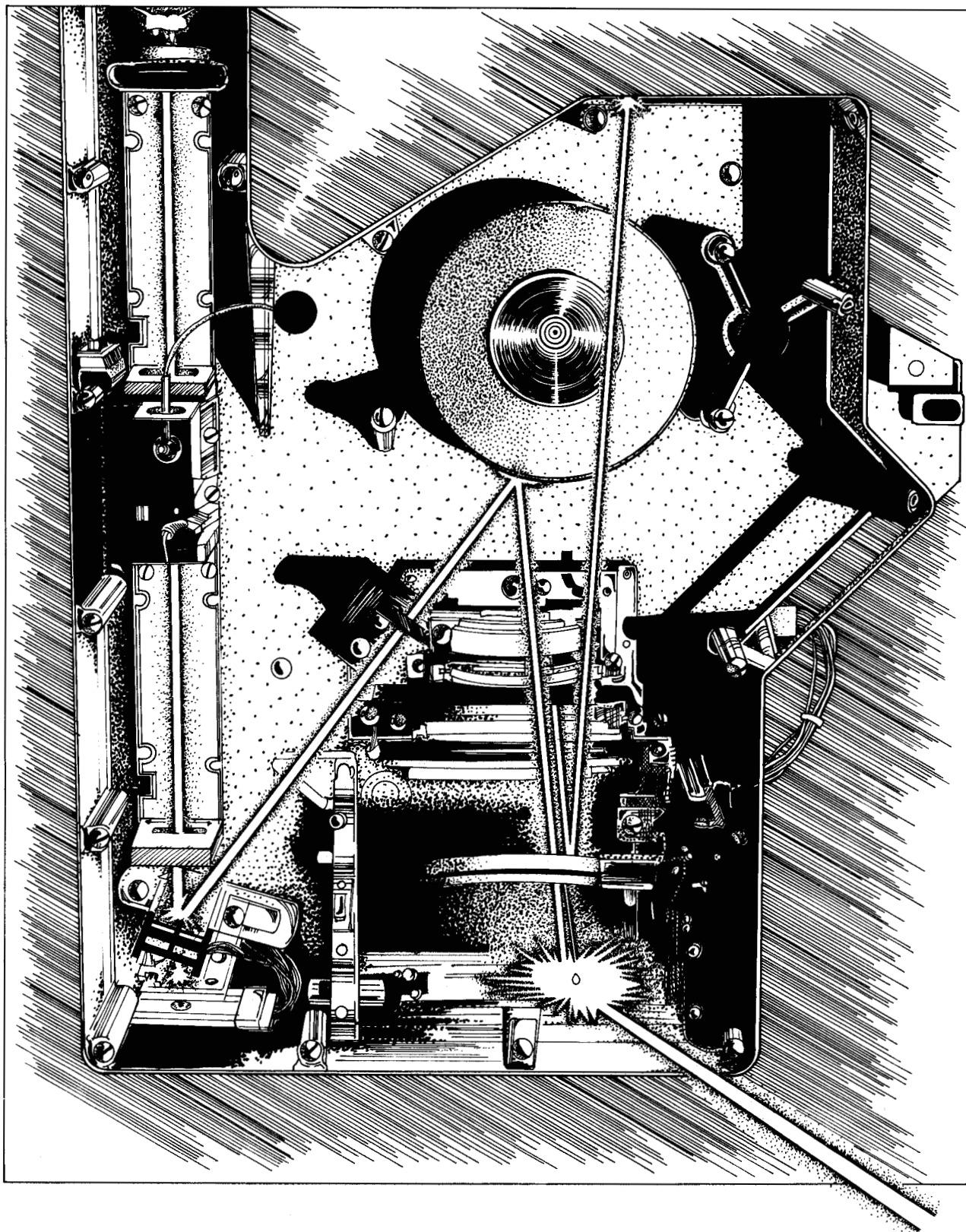
References

1. F. J. Furman and H. J. Kistner, "Wire Printer," U.S. Patent 2,785,628, 1957.
2. B. J. Greenblott, "A Development Study of the Print Mechanism on the IBM 1403 Chain Printer," *Trans. AIEE* (Part 1) **81**, 500-508 (1963).
3. F. M. Demer and E. J. Grenchus, "High Speed Printer Apparatus," U.S. Patent 2,993,437, 1961.
4. V. R. Simpson and T. W. Thompson, "Continuous Type Belt," U.S. Patent 3,041,964, 1962.
5. A. W. Mills, F. J. Furman, and E. J. Rabenda, "Paper Feeding Device," U.S. Patent 2,531,885, 1950.

6. J. E. Drejza, "Printer Apparatus Having Print Force Control," U.S. Patent 3,144,821, 1964.
7. A. A. Dowd, R. Nelson, and M. A. Henkel, "The IBM 1443 Printer," IEEE Conf. Paper CP 63-1127, available from the IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08554.
8. A. C. Cooper and A. A. Dowd, "Type Carrier for High Speed Printer," U.S. Patent 3,209,682, 1965.
9. J. M. Cunningham, "Type Carrier Device," U.S. Patent 3,224,366, 1965.
10. J. M. Cunningham, "Print Hammer Mechanism and Pressure Control Means in High Speed Printers," U.S. Patent 3,241,480, 1966.
11. J. M. Cunningham, "Type Mounting Means for High Speed Front Printer," U.S. Patent 3,653,321, 1972.
12. J. E. Drejza and D. F. Manning, "Incrementing Platen," U.S. Patent 3,576,164, 1971.
13. E. Lennemann and W. Sakmann, "Impact Line Printing: Improvement of a Proven Technology," *Computer* (IEEE Computer Society) 8, 16-27 (1975).
14. P. A. Engel, H. C. Lee, and J. L. Zable, "Dynamic Response of a Print Belt System," *IBM J. Res. Develop.* 23, 403-410 (1979).
15. P. A. Brumbaugh, R. H. Harrington, S. E. Nemier, and T. C. Nielsen, "Wire Matrix Print Head," U.S. Patent 3,672,482, 1972.
16. D. J. Darwin, B. Griffing, and H. Kiel, "Dot Printing Apparatus," U.S. Patent 3,897,865, 1975.
17. J. H. Meier and J. W. Raider, "Interposer for Disk Printer," *IBM J. Res. Develop.* 23, 392-395 (1979).

Received April 24, 1980; revised August 26, 1980

The authors are located at the IBM System Products Division laboratory, P.O. Box 6, Endicott, New York 13760.



Laser technology in the IBM 6670 Information Distributor